Migration of fenestrated aortic stent grafts

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Objective: **This article reports the incidence, timing, and related sequelae for proximal and distal migration of the Zenith Fenestrated AAA Endovascular Graft (Cook Medical, Bloomington, Ind) used to treat abdominal aortic aneurysms.**

Method: **A prospectively maintained database at a tertiary referral hospital was used to identify 83 patients who underwent endovascular repair using the Zenith fenestrated stent graft. Inclusion criteria included a postoperative computed tomography (CT) scan within 6 weeks of implantation and at least one additional follow-up CT scan (>5 months) available electronically at our institution. Eligible patients underwent assessment of stent graft migration using a CT-based central luminal line (CLL) technique. The proximal and distal margins of the stent graft were measured using CLLs relative to vascular landmarks on all available follow-up CT scans. Migration was defined as stent graft movement ≥4 mm.**

Results: **Fifty-five patients were included in this study, mean age was 74 ± 7 years, and 89% were men. Mean preoperative aneurysm diameter was 67 ± 9 mm. In these 55 patients, fenestrations were applied to 162 target vessels with the commonest design accommodating two renal arteries (RAs) and the superior mesenteric artery (SMA). Median follow-up was 24 (range, 5-97) months; 80% of patients (n = 44) had both the proximal and two distal attachment sites assessed for evidence of migration. Twelve iliac limbs in 11 patients were excluded from analysis due to occlusion of one internal iliac artery precluding CLL assessment (n = 7), or image quality issues (n = 5). Using CLLs and based on those patients who exhibited migration, the median proximal and distal migration distances were +5.0 (range, +4.0 to +8.1) mm and −5.0 (range, −4.3 to −21.3) mm, respectively. Kaplan-Meier analysis for proximal migration revealed migration rates of 14% and 22% at 12 and 36 months, respectively. Distal migration rates were lower at 3% and 8%, respectively. There have been no incidences of late rupture or open conversion. Of the patients with proximal migration, two patients lost a single target vessel (two RAs) and three patients were reported to have target vessel stenosis (two SMAs, one RA). These cases did not require reintervention.**

Conclusions: **Both suprarenal fabric extension and visceral artery stenting are known to provide additional fixation for fenestrated aortic stent grafts. Despite this, minor proximal migration still occurs in up to one quarter of fenestrated endovascular repair patients by 4 years. We believe this is mainly due to the engagement of the barbs of the anchoring stent. Distal migrations occur with lower frequency. (J Vasc Surg 2013;57:1543-52.)**

Twenty-five to seventy-five percent of all abdominal aortic aneurysms (AAAs) are anatomically unsuitable for standard infrarenal endovascular repair.[1,2] Complex endovascular techniques, such as fenestrated endovascular repair (FEVAR), have been developed for these situations.

Fenestrated stent grafts are subject to the same hemodynamic forces that have resulted in migration of standard infrarenal stent grafts.[3] Movement at the proximal seal zone of a fenestrated stent graft could result in loss of alignment between the fenestrations and the target vessel ostia. This may result in compromise of blood flow to the target vessels and/or loss of an aortic seal.

Early identification of any migration is critical. Recognition can alert the clinician to the presence of device instability and may allow early reintervention which may avert serious clinical sequelae.[4] Migration of a fenestrated stent graft has been previously reported.[5-10] In these short- and midterm reports, device migration is generally poorly defined and rates are based on cases resulting in clinical signs or requiring reintervention.

Migration of an infrarenal stent graft is often classified using the Society for Vascular Surgery/International Society for Cardiovascular Surgery reporting standards as any movement ≥1.0 cm or that caused symptoms or required reintervention.[11] This definition is likely to be insufficient for fenestrated stent grafts where smaller movements have been associated with sequelae.[8] Modern multidetector computed tomography (MDCT) scanning, when combined with a validated measurement technique,[12] has been shown to allow the quantification of more subtle levels of migration.

Cephalad forces acting on the iliac limbs[13] can also induce migration. Iliac limb migration, although infrequent, can occur at any time point.[14] As with proximal fenestrated stent graft migration, the incidence and consequences of

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iliac limb migration are not well understood. This report seeks to quantify the incidence, timing, and effects of both proximal and distal migration in patients with fenestrated stent grafts.

METHODS

Study design and patient sample. This is a retrospective review of prospectively collected data for all patients treated for short necked and juxtarenal AAAs with a custom-designed fenestrated device based on the Zenith system (Cook Inc, Bloomington, Ind). Research ethics approval was obtained, and patients were considered for inclusion if they had a fenestrated device implanted between the start of our fenestrated program in 2003 and 2010. Patients were required to have had a baseline (first) postoperative CT scan and at least one additional CT scan (minimum of 5 months from the baseline) available in Digital Imaging and Communications in Medicine (National Electrical Manufacturers Association, Rosslyn, Va) imaging format.

Image acquisition and reconstruction. Follow-up imaging studies were typically undertaken within 1 month, then at 6 and 12 months, and then annually thereafter. MDCT studies of the abdomen and pelvis were acquired using a Siemens Somatom Sensation 16 (Siemens, Erlangen, Germany). Collimation was set to 2.0 mm with a 1.0 mm reconstruction interval. Acquisitions followed intravenous injection of 100 mL ioversol (Optiray 300; Mallinckrodt, Hazelwood, Mo) at 5 mL/s and were initiated using bolus tracking software. Aortic enhancement at the level of the 12th thoracic vertebra must have exceeded 120 HU. Data were reconstructed using a B20f kernel and transferred to a workstation (Kodak Carestream PACS, 10.2; Kodak, Rochester, NY) for analysis.

Migration definition. Our definition of stent graft migration was derived from previously published work.[12] These experiments included an assessment of intra- and interobserver variability for the measurement technique. In summary, migration was defined as cranial or caudal movement of the device, relative to a vascular landmark of ≥4 mm. Migration assessments included an evaluation of both the proximal and both distal landing zones. Component separation was defined as any movement between the proximal fenestrated component and the distal bifurcated part.

Migration analysis. A central luminal line (CLL) was created using the semiautomated CLL algorithm on the workstation. The location of the CLL within the central channel of the vessel lumen was confirmed by scrolling through multiplanar reformatted images. Reconstructions perpendicular to the CLL were also evaluated to confirm exact locations when undertaking measurements (Figs 1 and 2). The proximal native vascular reference point was the superior mesenteric artery (SMA). The distance between the inferior border of the SMA and the first appearance of the stent graft (two struts) was measured. The inferior border of the SMA was defined as the first oblique axial CLL reformatted image where there is clear separation of the SMA from the aortic wall (Fig 1). The iliac bifurcation was used as the distal reference point and was defined as the first oblique axial CLL reformatted

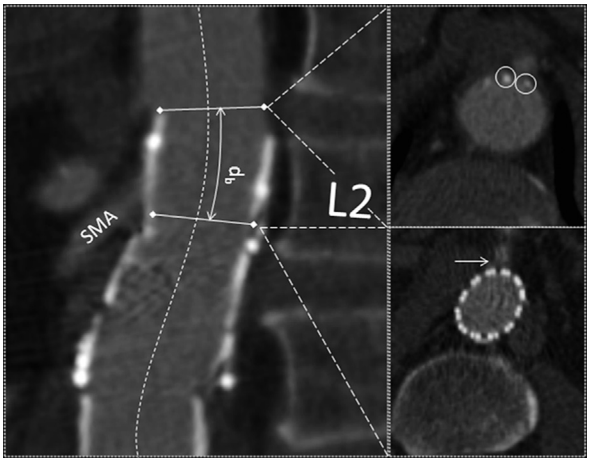


Fig 1. A proximal measurement (d_b) has been undertaken using the baseline central luminal line (CLL) computed tomography (CT) image. The first oblique axial reformatted image, where at least two stents struts were visible (*circles*), was considered indicative of the proximal stent position. The first reformatted slice where there was a clear space between the superior mesenteric artery (*SMA*) and the aortic wall was considered the inferior border of the reference vessel (*arrow*). Lines perpendicular to the CLL demonstrate the projection of each oblique reformat and indicate the central point within each reconstructed slice.

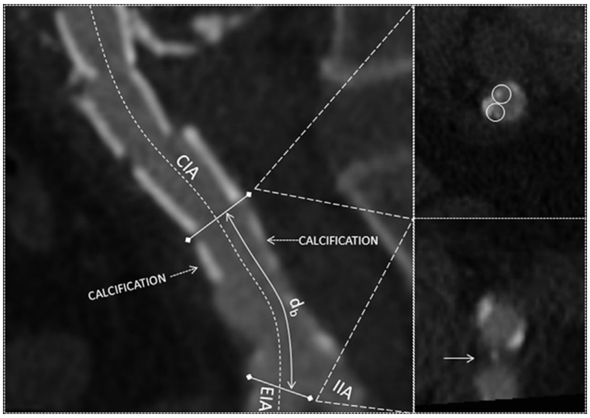


Fig 2. A central luminal line (CLL) computed tomography (CT) measurement (d_b) taken at the distal landing zone on the baseline CT scan. The position of the distal stent graft is recorded relative to the bifurcation of the common iliac artery (*CIA*). The first oblique axial reformatted image where at least two stents struts were visible was considered indicative of the distal stent position (*circles*). The first reformatted slice where there was a clear space between the external iliac artery (*EIA*) and the internal iliac artery (*IIA*) was considered the level of the iliac bifurcation (*arrow*). Lines perpendicular to the CLL demonstrate the projection of each oblique reformat and indicate the central point within each reconstructed slice.

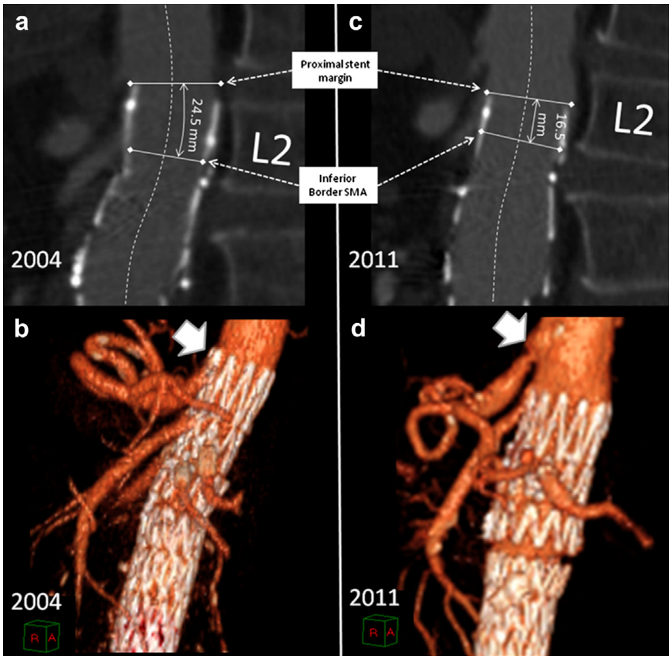


Fig 3. A central luminal line (CLL) image from the 2004 first postoperative follow-up computed tomography (CT) scan **(a)**, the proximal portion of the fenestrated stent graft was sitting 24.5 mm above the inferior border of the superior mesenteric artery (*SMA*). On the 2004 three-dimensional (3D) volume-rendered (VR) image **(b)** the top of the bare stent struts were in line with the origin of the celiac axis (*arrow*). By 2011, the stent graft had moved caudally 8.0 mm, the proximal margins of the device are now resting 16.5 mm above the inferior border of the SMA **(c)**. On the 2011 3D VR image **(d)** there is clear evidence of caudal migration with an absence of stent graft covering the infraceliac aorta (*arrow*).

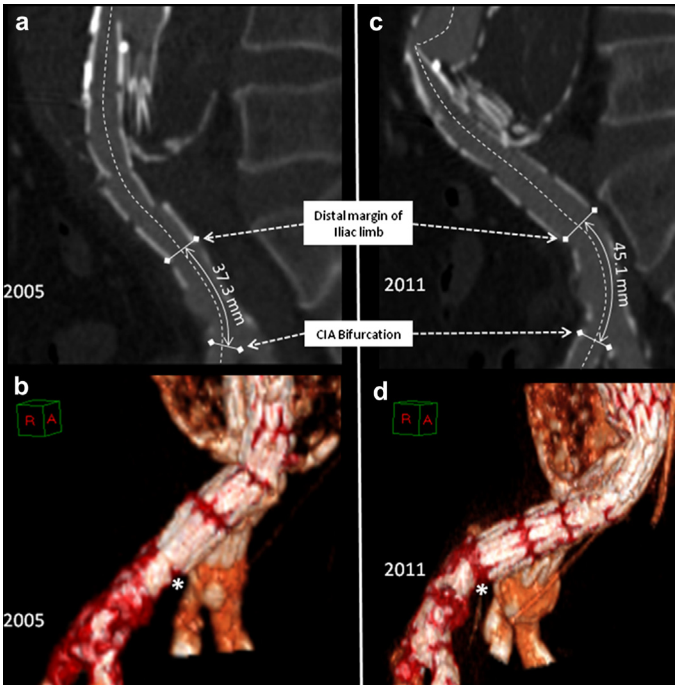


Fig 4. A central luminal line (CLL) **(a)** and three-dimensional (3D) volume-rendered (VR) images **(b)** from the 2005 first postoperative follow-up computed tomography (CT) scan, the distal portion of the left iliac limb was sitting 37.3 mm above the bifurcation of the right common iliac artery (*CIA*). By 2011 the limb had moved cranially 7.8 mm, the distal margins of the device are now resting 45.1 mm above the CIA bifurcation **(c)**. On the VR images **(d)** cranial movement of the device between the two time points can clearly be seen in relation to vascular calcification (*).

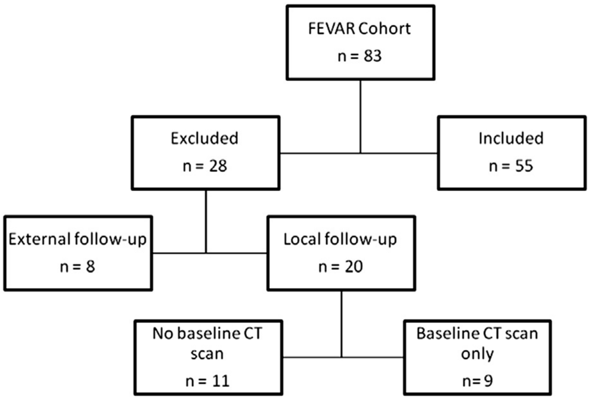


Fig 5. Study inclusions and losses. *CT,* Computed tomography; *FEVAR,* fenestrated endovascular repair.

image where there was clear separation of the internal and external iliac arteries (Fig 2). Length measurements were obtained using the CLL to measure from the proximal stent graft to the SMA and from the distal extremes of the stent graft to the iliac bifurcation (bilaterally) using the first postoperative CT scan. Each CLL measurement was then compared with the same measurement on all available subsequent CT scans. Measurement differences between the baseline and subsequent CT scans, for the same anatomical location, would be suggestive of device migration. Caudal migration of the stent graft was indicated by a plus sign and cranial movement was indicated using a minus sign. Measurements were recorded to 1/10 mm.

Using the CLL data, any patient meeting our definition of device migration was subjected to further scrutiny. This included visual analysis of the reconstructed aortic segment from which specific landmarks were identified within the aortic wall (eg, calcification). These images, in addition to the CLL data, were assessed by two observers to confirm whether the device had migrated with respect to its initial implanted position. Examples are provided in Figs 3 and 4.

Statistical analysis. SPSS Statistics 20.0 (IBM, Armonk, New York) was used for the statistical analysis. Variables are expressed as mean ± standard deviation in cases of distributions that are approximately normal. The median plus the range were reported if the data were not approximately normally distributed. Migration distances were only reported for patients who met our migration definition. Kaplan-Meier methods using interval censoring were used to construct survival curves for proximal, distal, and any device migration. To facilitate this survival, data were computed with the R v2.14.1 statistical programming language (R Foundation for Statistical Computing, Vienna, Austria). Estimations of migration-free survival were generated using nonparametric maximum likelihood estimations to deal with interval censored data.[15,16] Differences between iliac limb types (ipsilateral/contralateral) were assessed by visual inspection of the curves. The effect of migration on target vessel

Table I. Study group demographics and risk factors

Patient characteristics	*Inclusions (n = 55), No. (%)*	*Exclusions (n = 28), No. (%)*
Mean age ± SD, years	74 ± 7	71 ± 8
Hypertension	30 (55)	14 (50)
Diabetes	5 (9)	4 (14)
Coronary artery disease[a]	32 (58)	15 (54)
Cerebrovascular disease[b]	8 (15)	6 (21)
Renal insufficiency[c]	8 (15)	4 (14)
ASA grade		
II	14 (25)	8 (29)
III	39 (71)	19 (68)
IV	2 (4)	1 (4)

ASA, American Society of Anesthesiologists; *SD,* standard deviation.
[a]Previous myocardial infarction, angina, or electrocardiogram evidence of ischemia.
[b]Previous stroke or transient ischemic attack.
[c]Preoperative serum creatinine >150 μmol/L.

Table II. Configuration of scallops and fenestrations used within the study group

	Unstented		*Stented*	
	Scallop	*Fenestration*	*Scallop*	*Fenestration*
CA	11			
SMA	33	1		13
Renal	3		4	97

CA, Celiac axis; *SMA,* superior mesenteric artery.

patency (stenosis, occlusion), endoleak (type I), aneurysm rupture, and the need for reinterventions was assessed.

RESULTS

A total of 83 patients with juxtarenal AAAs were treated with fenestrated stent grafts during the study period. Eight patients were followed up in other hospitals and have therefore been excluded. Other losses are summarized in Fig 5. There were a total of 55 patients included, 49 men and six women with a mean age of 74 ± 7 years. Preoperative comorbidities and risk factors are listed in Table I. Eighteen (33%) patients died during follow-up; review of our vascular database indicated that none was aneurysm-related. Mean maximal AAA diameter was 67 ± 9 mm. The total number of fenestrations was 162; the most common combination included two small renal artery (RA) fenestrations and an SMA scallop (Table II).

Of 55 patients with a median follow-up of 24 months (range, 5-97 months), 10 (18.2%) showed evidence of proximal migration (median distance, +5.0 mm; range, +4.0 to +8.1 mm). Graft-related events and reinterventions are displayed in Table III. Based on a follow-up of 130.2 person-years, this produced a proximal migration rate of one migration per 12.5 person-years of follow-up. Kaplan-Meier survival analysis estimated that the probabilities of being free from proximal migration at 12 and 36

Table III. Outcomes of patients with CT evidence of proximal stent graft migration

Patient/ device	*Time to migration, months*	*Migration distance, mm*	*Pre-op AAA diameter, mm*	*Latest AAA diameter, mm*	*Change in AAA diameter, mm*	*Endoleak*	*TV event*	*Component separation*	*Outcome*
1 (1S 2F)	36.9	+8.0	59	40	−19	No	LRA stenosis (Bridge Assurant, uncovered)	No	LRA stenosis on first post-operative CT. Alive at LFU (8 years), renal function stable, no reinterventions.
2 (1S 2F)	36.8	+7.4	70	39	−31	Type II	No	No	Clinical sequelae/reintervention free at LFU (5 years). Died − NARC.
3 (1S 3F)	24.3	+6.2	80	46	−34	No	No	No	Clinical sequelae/ reintervention free at LFU (6 years). Died − NARC.
4 (1S 2F)	84.7	+6.2	69	87	+18	Type II	No	Yes	Modular distraction of the main body. Bridging stent graft was implanted at 36 months. No further complications/ reintervention. Patient alive at LFU (9 years).
5 (1S 2F)	24.2	+5.3	63	35	−28	Type II	SMA stenosis (unstented scallop)	No	Clinical sequelae/reintervention free at LFU (8 years). Died − NARC.
6 (1S 2F)	30.5	+5.0	58	59	+1	No	LRA occlusion (Jostent, covered)	No	LRA lost on 2-year CT. Migration reported 6 months later. Serum creatinine rose from 93 to134 mmol/L during follow-up. No reintervention. Patient withdrew from follow-up after 5 years, died − NARC.
7 (1S 2F)	11.3	+4.7	59	57	−2	No	LRA occlusion (Advanta V12, covered)	No	Minor renal artery stenosis and calcification on preoperative CT. LRA occlusion because of continuation of renovascular disease. Stable renal function, patient alive at LFU (2 years), no reintervention.
8 (1S 2F)	62.8	+4.1	78	70	−8	No	No	Yes	Modular distraction of the main body overlap at 4 years. Distraction led to kinking of the contralateral limb and was treated with a Wallstent. Patient alive and complication/further reintervention free at LFU (7 years).
9 (1S 2F)	11.7	+4.1	64	46	−18	No	SMA stenosis (Advanta V12, covered)	No	Alive/free from clinical sequelae/reintervention at LFU (2 years).
10 (1S 1F)	13.0	+4.0	71	77	+6	Type II	No	No	Alive/ free from clinical sequelae/reintervention at LFU (2 years).

AAA, Abdominal aortic aneurysm; *CT,* computed tomography; *F,* stented fenestration; *LFU,* last follow-up; *LRA,* left renal artery; *NARC,* nonaneurysm-related cause; *S,* unstented scallop; *SMA,* superior mesenteric artery; *TV,* target vessel.
Changes in AAA diameter: negative values denote a reduction in AAA diameter whereas positive values highlight an increase. Target vessel stent data: Jostent; Jomed International, Helsingborg, Sweden; Advanta V12; Atrium, Hudson, NH; Bridge Assurant; Medtronic, Santa Rosa, Calif.

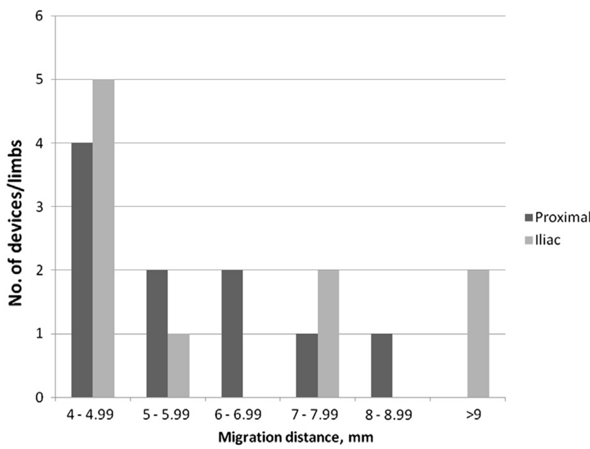
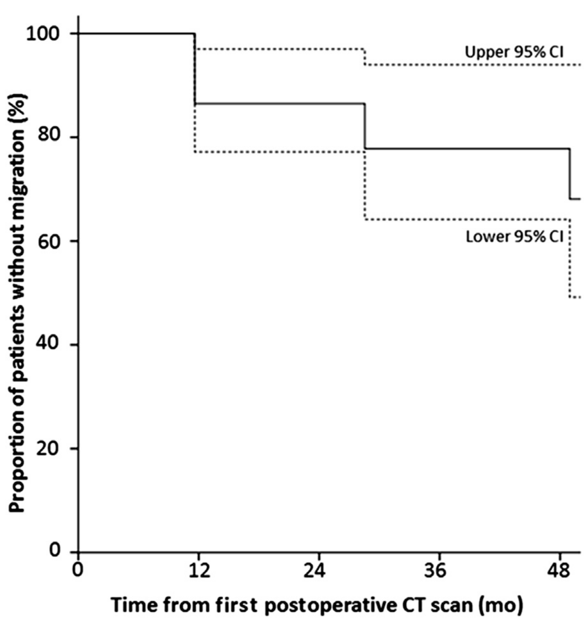


Fig 6. Frequencies of proximal and distal stent graft migration. In the two cases of iliac limb migration >9 mm, one case had 10.6 mm and the second case had 21.3 mm of cranial movement.



Time, mo	6	12	24	36	48
n. at risk	50	46	25	15	8
SE	0.05	0.05	0.05	0.08	0.11

Fig 7. Kaplan-Meier survival analysis illustrating freedom from proximal stent graft migration. *CI,* Confidence interval; *CT,* computed tomography; *SE,* standard error.

months were 86% (95% CI, 77%-97%) and 78% (95% CI, 64%-94%), respectively. The magnitude and timings of proximal migration are illustrated in Figs 6 and 7.

Using data from 55 patients, a total of 98 iliac limbs were assessed for the presence of distal migration. In 11 patients (12 common iliac arteries), a CLL was unable to be constructed. This was either due to an occluded internal iliac artery (n = 7) or image quality issues (n = 5). Of the 98 iliac limbs assessed, 10 (nine patients) showed evidence of migration. Median distal migration was −5.0 (range, −4.3 to −21.3) mm (Table IV; Fig 6) with no clinical sequelae or reinterventions. Based on an iliac limb follow-up of 124.1 person-years, there was a distal migration rate of one migration per 14 person-years of follow-up. The probabilities of a patient being free from distal migration at 12 and 36 months were 97% (95% CI, 94%-100%) and 92% (95% CI, 87%-99%), respectively (Fig 8). Analysis on an individual iliac limb basis (ipsilateral/contralateral) estimated that the probabilities of a patient being free from migration at 12 and 36 months were 90.8% (95% CI, 81.1%-100%%)/96.0% (95% CI, 90.7%-100%) and 80.0% (95% CI, 64.5%-99.3%)/90.7% (95% CI, 80.0%-100%), respectively (Fig 9). Bilateral iliac limb migration was seen in one patient, and combined proximal and at least one iliac limb migration was seen in three patients. Freedom from any (proximal/distal) migration at 12 and 36 months were 81% (95% CI, 71%-93%) and 64% (95% CI, 49%-84%), respectively (Fig 10).

For those with CT evidence of proximal migration, two patients had migration identified on the last follow-up CT scan. For the remaining eight patients, there were only minor amounts of further migration (mean, +0.5 ± 0.8 mm) during the remaining follow-up (mean, 36 ± 15 months). Distally, three out of 10 limbs were identified as migrated at last follow-up. For the remaining seven, there was also only a small amount of further migration (mean, −1.6 ± 1.4 mm) over a mean 27 ± 1 months.

DISCUSSION

Positional stability of a fenestrated stent graft is essential to ensure long-term procedural success. With the possibility of target vessel compromise and aneurysm reperfusion, migration of a fenestrated stent graft has raised significant concerns within the vascular community. Over recent years there has been an increase in short- and midterm outcome data for FEVAR.[5-9] There is still, however, little detailed information regarding migration of fenestrated stent grafts.

Based on Kaplan-Meier analysis, 14% of our patients had an estimated probability of proximal migration at 12 months; by 36 months, this had increased to 22%. Iliac limb migrations were less frequent with 12- and 36-month probabilities of 3% and 8%, respectively. Comparison with the literature is problematic, as most reports provide only limited references to device migration.[5-10] Migration rates of 1%-7%[5,7] have been reported and are based on cases with clinical sequelae or requiring reintervention. Troisi et al[10] reported a higher incidence (24%), all requiring reintervention. Their incidence was based on a mix of branched, fenestrated, and combined branched/fenestrated devices with migration only highlighted in cases with a type I endoleak. Eight cases of in-stent stenosis or occlusion were also reported. It was not clear if any of these resulted from device migration. If we assume a similar classification, then our migration

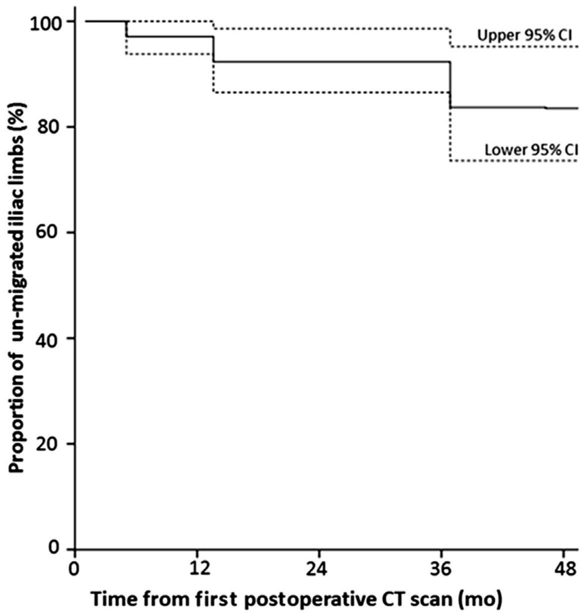
Table IV. Outcomes of patients with CT evidence of migration of iliac limb migration.

Case	*Limb*	*Time to migration, months*	*Migration distance, mm*	*Pre-op AAA diameter, mm*	*Latest AAA diameter, mm*	*Changes in AAA diameter, mm*	*Endoleak*	*Iliac reintervention*	*Outcome*
1 (8)	Ipsi	37.1	−21.3	78	70	−8	No	No	Alive at LFU (7 years) − see proximal patient 8. No IRSI.
2	Contra	5.3	−10.6	70	61	−9	No	No	Alive at LFU (4 years), no complications/reinterventions.
3 (5)	Ipsi	48.4	−7.7	63	35	−28	No	No	Died − NARC (8 years) − see proximal patient 5. No IRSI.
4	Contra	5.4	−7.5	58	53	−5	Type II	No	Alive at LFU (3 years), no complications/reinterventions.
5	Contra	23.9	−5.0	57	60	+3	No	No	4-year follow-up, died − NARC. No complications/reinterventions.
6	Ipsi	12.2	−4.9	74	68	−6	No	No	Alive at LFU (3 years), no complications/reinterventions.
7 (8)	Contra	62.8	−4.6	78	70	−8	No	No	Alive at LFU (7 years) − see proximal patient 8. No IRSI.
8 (4)	Ipsi	89.5	−4.4	69	87	+18	No	No	Alive at LFU (9 years) − see proximal patient 4. No IRSI.
9	Contra	38.0	−4.4	85	86	+1	Type II	No	Alive at LFU (4 years), no complications/reinterventions.
10	Contra	23.3	−4.3	67	57	−10	Type II	No	2-year follow-up, died − NARC. No complications/reinterventions.

AAA, Abdominal aortic aneurysm; *Contra,* contralateral; *CT,* computed tomography; *Ipsi,* ipsilateral; *IRSI,* iliac-related secondary intervention; *LFU,* last follow-up; *LRA,* left renal artery; *NARC,* nonaneurysm-related cause; *SMA,* superior mesenteric artery.
Changes in AAA diameter: negative values denote a reduction in AAA diameter whereas positive values highlight an increase. Numbers enclosed by the parentheses in the first column correspond to any related proximal migration cases in Table III.

rate is 9%; two patients lost a single RA and three patients had stenosis (two SMAs, one RA). The two cases of RAs occlusion were, however, deemed not to result from migration. Patient 6 had patent RAs on both preoperative and first postoperative CT angiograms. A left RA occlusion was reported at 2 years; it was a further 6 months before device migration met our definition. Analysis of follow-up imaging demonstrated no evidence of stent crushing or fracture. Following occlusion, the patient's serum creatinine levels rose from 94 to 134 mmol/L, without any need for dialysis. Because of comorbidities, the patient withdrew from follow-up at 5 years and has since died from a nonrelated cause. Patient 7 also had a left RA occlusion detected at 2 years, migration was detected a further 12 months after the vessel occlusion. During follow-up, CT and ultrasound demonstrated a continual reduction in left RA blood flow and associated renal atrophy. A minor RA stenosis with vessel calcification was seen on the preoperative CT scan. The occlusion was, therefore, believed to be a continuation of the patient's renovascular disease. Serum creatinine levels are stable (100 mmol/L), and the patient was alive at last follow-up. Stent graft migration with shuttering of the fabric over the vessel ostium is a valid cause of target vessel loss. Other factors include the misalignment of a fenestration during deployment, preoperative vessel quality, progression of atherosclerosis, distal embolization, and intimal hyperplasia. Perhaps more importantly, in our series, there have been no cases of proximal type I endoleak, rupture, or conversion to open repair.

From our series, proximal migration occurred at a mean rate of 8% per year, peaking by the end of the first year at 14%. This early peak may be the result of barb engagement as an initial phase of stent graft movement has been associated with barb engagement.[3] Zhou et al[3] reported that a significantly smaller force was needed to engage the barbs into the aortic wall and following this there is a period of high resistance to movement. This *in vitro* work is important in that they compared a standard infrarenal device with a single stented fenestrated device. The addition of a stented fenestration increased the force needed for initial displacement from 4.3 to 11.5 N (10% oversizing). A further, final phase of displacement required an extra 6.4 and 16.8 N, for standard and fenestrated devices respectively. From Zhou's work, it is clear that fenestrated stent grafts offer higher fixation. The effect of oversizing on device fixation was also investigated. For standard devices, increasing the oversizing from 5% to 10% and 5% to 20% required an extra 0.9 (27%) and 4.3 N (127%) of force for initial displacement. For a fenestrated device, the extra force needed was less, 1 (9%) and 1.6 N (16%). Final displacement of a fenestrated device required an increase of 5.7 and 10.5 N, for 10% and 20% respective oversizing compared with 2.7 and 8.7 N for a standard device. Zhou's work concluded that the protective benefits of oversizing a fenestrated device (>10%) are reduced in



Time, mo	6	12	24	36	48
n. at risk	88	74	45	30	25
SE	0.02	0.03	0.06	0.06	0.10

Fig 8. Freedom from iliac limb migration. *CI,* Confidence interval; *CT,* computed tomography; *SE,* standard error.

comparison with a standard device. They only investigated the additional fixation provided by a single stented fenestration and did not investigate whether there are additional benefits from using multiple stented fenestrations. In our series, all 10 cases of proximal migration had stent graft configurations, which included at least one stented renal fenestration (Table III). A combination of barbs, fabric extension into the suprarenal aorta, bare proximal stent struts, and a separate proximal component are all likely to contribute to the low incidence of proximal migration.

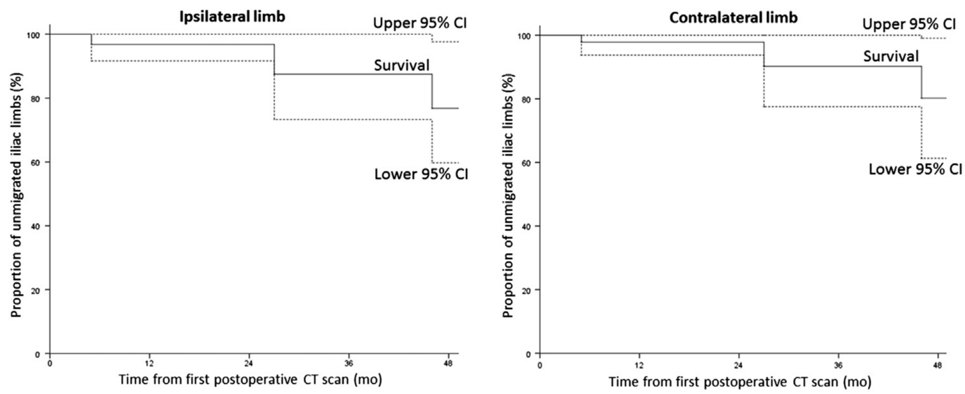
Other factors that may predict migration are important. For standard devices these are well documented and include AAA neck enlargement,[17] angulation,[18] the use of proximal barbs,[19] stent graft oversizing,[3] and the length of common iliac artery utilization.[20] For fenestrated stent grafts, the quantification of oversizing may be difficult. The sealing stent is likely to oppose the aortic wall over a range of aortic diameters. What may be a 20% oversizing at the SMA may reduce to 15% at the level of the renal arteries or vice versa. In our series, device oversizing was always in line with the manufacturer's instructions for use. Follow-up complications have also been linked, Li and Kleinstreuer[21] reported that the presence of endoleaks may mitigate the risk of stent graft migration. More general variables such as hypertension[22] have also been reported but as with oversizing may be harder to define. Categorizing a patient as hypertensive is difficult since numerous definitions exist,[23] and measurements can vary depending on the circumstances in which they are acquired.[24] To provide the best opportunity to identify predictive factors, an appropriately designed study is needed. This must include a carefully considered set of definitions, appropriate measurement techniques, and suitable numbers of migration and nonmigration cases.

Distal migrations peaked between years 3 and 4 with an annual migration rate of 8%. With a lack of published data on the timings of distal migration, it is difficult to compare data between studies. In our series, migrations were almost equally distributed between ipsilateral (n = 4) and contralateral (n = 6) limbs. There were no cases of distal type I endoleaks irrespective of the presence of migration.

The separate proximal component of the Zenith fenestrated stent graft should help reduce the effects of the caudally directed forces experienced at the aortic bifurcation. This should help reduce the likelihood of migration to the proximal component. Agreeing with this, Ziegler et al[6] stated that the lower rate of fenestrated stent graft migration with the Zenith device is a result of a separate proximal and bifurcation components.[26] Although helpful in opposing proximal migration this design brings the added risk of component separation between the proximal fenestrated and distal bifurcated pieces. With the additional fixation from target vessel stents, it is likely that we would see a greater incidence of component separation than proximal stent graft migration. Main body component distraction did occur in several of our patients. All were successfully managed with either the implantation of a bridging stent or using follow-up imaging. Conservative management was used if the movement had ceased and there was still good overlap between components.

Small movements have been associated with crushing of a target vessel stent and vessel occlusion.[5,8] In a series reported by Verhoeven et al, migrations of <5 mm were suspected in three cases; two of these resulted in a RA occlusion.[8] There is clearly a need to identify more subtle levels of migration. The Cleveland group has already adopted this principle. In their series, migration was defined as movement greater or equal to twice the CT slice thickness or causing a clinical event. With the majority of centers having access to thin-slice MDCT, it is perhaps time to re-define stent graft migration.

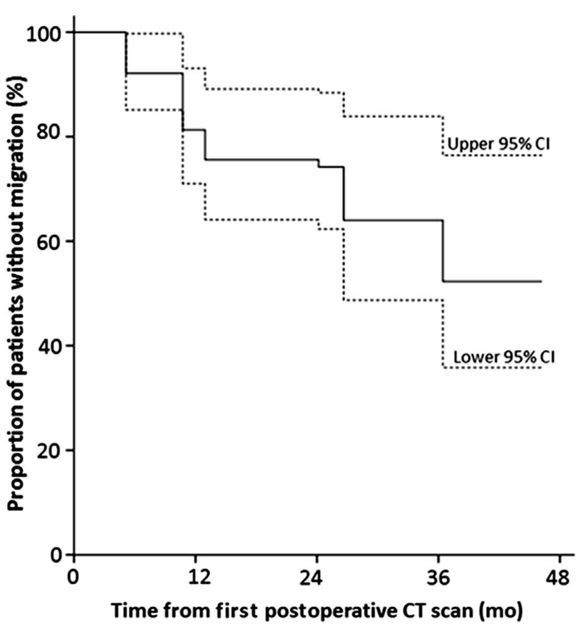
In reporting this study, we accept that there are limitations. Thirty-four percent of our patients were excluded; this was primarily due to a lack of available follow-up CT scans. Ten percent of patients had follow-up at another institution, and whereas it may have been possible to locate their CT data, it is likely that this may have been acquired to a different protocol. To facilitate the detection of subtle stent graft migration, all patients were followed up to the same CT protocol using the same CT equipment. O'Neill and colleagues[25] highlighted potential problems comparing studies that have been acquired to different CT protocols. Differences in stent graft position during the respiratory and cardiac cycles may also induce some measurement errors. Vos et al highlighted that there can



Time, mo	6	12	24	36	48
n. risk	44	44	17.6	17.6	13.9
SE	0.03	0.03	0.07	0.07	0.10

Time, mo	6	12	24	36	48
n. risk	50	50	17.9	17.9	13.5
SE	0.02	0.02	0.06	0.06	0.10

Fig 9. Freedom from iliac limb migration (ipsilateral vs contralateral limbs). Upon visual inspection, there were no apparent differences between limb types. *CI,* Confidence interval; *SE,* standard error.



Time, mo	6	12	24	36	48
n. at risk	49	41	27	15	7
SE	0.04	0.06	0.06	0.09	0.10

Fig 10. Freedom from any device migration. *CI,* Confidence interval; *CT,* computed tomography; *SE,* standard error.

be up to 1.99 mm of cranio-caudal movement of the AAA when imaged using cine magnetic resonance imaging.[26] The movement of a deployed fenestrated stent graft in relation to the aortic wall is currently undefined. However, temporal changes in stent graft position resulting from differences in the respiratory and cardiac cycle could generate cases of pseudo-migration. We would argue that by using a migration definition of movement ≥4 mm, this is likely to reduce the likelihood of any temporal errors. Rotational movement of a fenestrated stent graft is also possible. Vessel occlusion and type III endoleaks have been attributed to lateral rotation of a fenestrated stent graft during follow-up.[6] Rotation of the proximal component is thought more likely to result from inadequate planning or rotational misalignment during deployment. In our study we did not assess rotational migration but we would recommend that clinicians actively scrutinize follow-up imaging for rotational shuttering.

Our diagnosis of migration was based on the quantification of stent graft positional changes and the visual verification of any movements by two observers. Visual verification included the cross-referencing of stent graft position against side-branches and aortic calcification. Other indices were also considered, including changes to the angulation of the target vessel stents. It was clear that in all our cases of proximal migration, the device was moving toward the renal arteries. Whether aortic elongation could mimic or mask cases of migration must also be considered. Few reports have discussed the issue of aortic elongation.[25,27] Litwinski et al[27] failed, in our opinion, to demonstrate that for some patients the aorta lengthened during follow-up. Their assumption was that if the length of aortic neck increased, and there was no change to the proximal fixation length (top of the stent graft to the start of the aneurysm) then this was indicative of aortic elongation. No evidence was provided that the distance between the caudal renal artery and the aortic bifurcation increased. It is possible, depending on measurement techniques and definitions that the aortic neck length could increase in a regressing aneurysm. The stent graft could still migrate but because of the regression the proximal fixation length would remain relatively static. In our experience, we would interpret any longitudinal movement of a stent graft in the aorta as migration. Other authors have raised concerns regarding possibility of aortic elongation.[25] In these situations, they too have supported the need for visually verifying cases of suspected migration.

CONCLUSIONS

Suprarenal fabric extension and visceral artery stenting are known to provide additional fixation for fenestrated aortic stent grafts. Despite this, minor proximal migration still occurs in up to one quarter of FEVAR patients by 4 years. We believe this is mainly due to the engagement of the barbs of the anchoring stent. Distal limb migrations are fewer, and overall there is a low incidence of migration related sequelae.

AUTHOR CONTRIBUTIONS

Conception and design: AE, SV, RM
Analysis and interpretation: MG
Data collection: AE, SV, JB, RF, JN
Writing the article: AE, MG, RM
Critical revision of the article: MG, RM, SV, JN, JB, RF
Final approval of the article: AE, MG, JN, JB, RF, SV, RM
Statistical analysis: AE, MG
Obtained funding: AE, MG
Overall responsibility: AE, RM

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